PROCEEDINGS OF SCIENCE

Radio spectral index images of the spiral galaxies NGC 0628, NGC 3627, and NGC 7331

Rosita Paladino*
Institut fur Astro-und Teilchenphysik- Innsbruck
E-mail: rosita.paladino@uibk.ac.at

Matteo Murgia
INAF - Astronomical Observatory of Cagliari
E-mail: matteo@ca.astro.it

Emanuela Orrú
Institut fur Astro-und Teilchenphysik- Innsbruck
E-mail: Emanuela.Orru@uibk.ac.at

We report on the spectral index analysis of three nearby spiral galaxies: NGC 0628, NGC 3627, and NGC 7331. We carried out new 327 MHz radio continuum observations with the Very Large Array. To obtain detailed spectral index maps, we complemented our data set with sensitive archival observations at 1.4 GHz. Since at these frequencies the contribution from thermal emission is likely to be minimized, the spectral index between 327 MHz and 1.4 GHz can be used to study the spectrum of the non-thermal emission. We compared spatially resolved radio spectral index images of galaxies and their IR distribution, to understand the cosmic ray's propagation mechanisms, and their correlation with star formation processes. Such a study is only now possible due to the unprecedented high spatial resolution and sensitivity of *Spitzer Space Telescope* at IR wavelengths. This work would be a starting point for the program of extending this kind of analysis to a large sample of galaxies.

Panoramic Radio Astronomy: Wide-field 1-2 GHz research on galaxy evolution - PRA2009
June 02 - 05 2009
Groningen, the Netherlands

*Speaker.

PoS(PRA2009)049

1. Introduction

It is well known that close correlations are observed between the synchrotron emission of spiral galaxies and several star formation tracers, like the H_α emission from ionized gas, the infrared radiation (IR) from thermal dust (e.g. [1]), and the CO emission from molecular clouds ([2], [3], [4], [5]). These correlations hold not only on global but also on local scales, down to hundreds of parsecs, within the disks of spiral galaxies ([6], [7]). The origin of these correlations is thought to be the massive stars formation, however the details of the physical mechanisms on how this occurs are not completely understood.

One main difficulty in the study of the non-thermal radio continuum is that the synchrotron radiation essentially traces the product of cosmic ray electrons (CRe) and magnetic field energy densities. A second source of uncertainty is related to the propagation mechanisms of CR, which are still poorly known. To understand the correlation between cosmic ray propagation and the sites of intense star formation, we compare spatially resolved radio spectral index images of galaxies and their IR distribution. Such a study is only now possible due to the spatial resolution and sensitivity at IR wavelengths provided by the *Spitzer Space Telescope*.

We present the results of the spectral index analysis of three nearby spiral galaxies, reported in [8]. This would be the starting point for the program of extending this kind of study to a large sample of galaxies. New VLA observations at 327 MHz and sensitive archival observations at 1.4 GHz have been used to obtain detailed spectral index images (α). At these frequencies the contribution from the thermal emission is likely to be minimized, then the spectral index can be used to study the spectrum of the non-thermal emission.

In the following we show the most important results, for further details see [8].

2. Local variations in the radio spectral index

To accurately determine the spectral index distributions we convolved the images at both frequencies to a round beam: We convolved NGC 0628 images to a $66''$ round beam, while we used a beam of $20''$ for NGC 3627 and NGC 7331. The primary beam correction was applied to the images at both frequencies. The spectral index images between 327 MHz and 1.4 GHy were obtained by considering only those pixels where the brightness was above 3σ at both frequencies. The dynamic range of images at 327 MHz is typically lower than the one at 1.4 GHz, therefore the cut in these spectral index images in most of the points is driven by the 327 MHz data. In left panels of Figures 1, 2, and 3 the color scale show the spectral index images, contours levels of the radio emission at 1.4 GHz are overlaid on the images.

The $66''$ beam of NGC 0628 partly hidden the spiral structure of the galaxy, however bright clumps in spiral arms in radio images correspond to flatter regions in the α image (Fig. 1). The spectral index image of NGC 3627 (Fig. 2) clearly shows that the bar and its bright ending regions have a flatter spectral index than the underlying disk. NGC 7331 (Fig. 3) shows an almost uniformly flat spectrum in the center and a steepening towards the peripheral regions of the disk.

For a quantitative analysis we measured the point-to-point brightness on the radio images at both frequencies. We overlaid regular grids of rectangular beam-sized boxes on the images and we averaged the brightness in each box, then we calculated the spectral index. We compared the

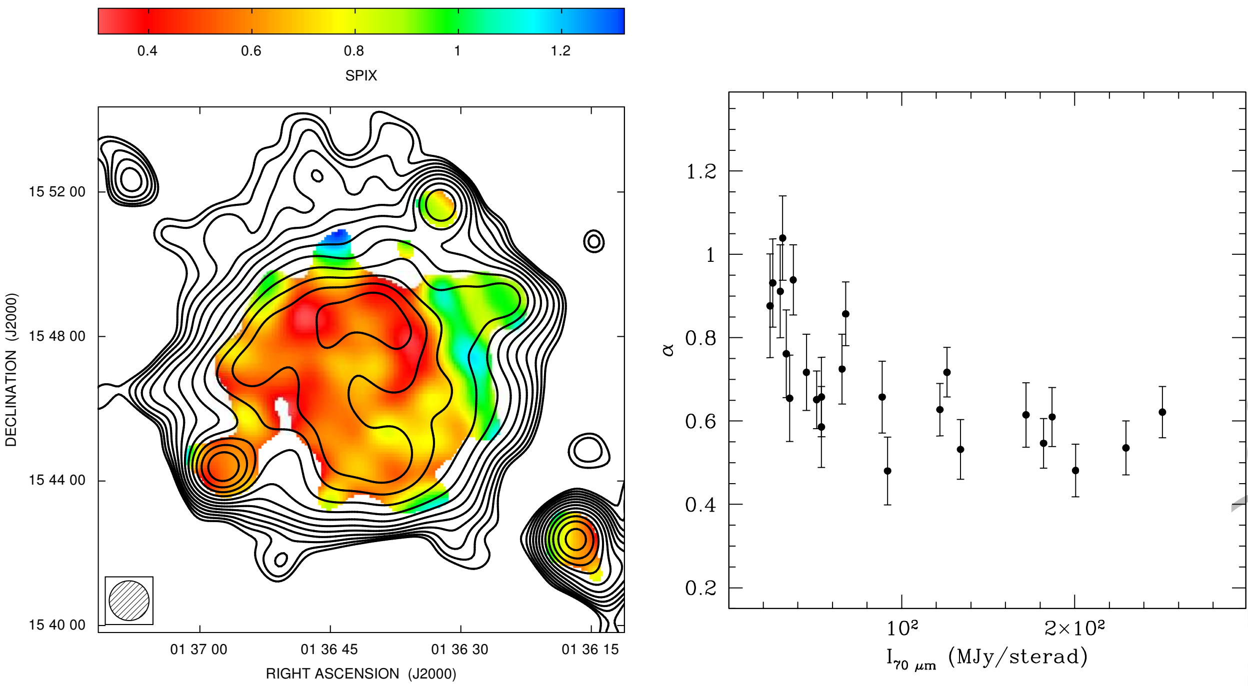

Figure 1: Galaxy NGC 0628 – *Left panel*: The color scale represents the image of the spectral index measured between 327 MHz and 1.4 GHz. Pixels with an intensity level above 3 σ at both frequencies have been considered. Contours levels of the radio image at 1.4 GHz, starting from 3 σ and scaling by a factor of $\sqrt{2}$, are overlaid on the image. The FWHM of this image is $66'' \times 66''$. *Right panel*: Point-to-point comparison between spectral index variation and IR-70 μm brightness. Only points exceeding 5 times the rms of the computed spectral index are shown. Figures taken from [8]

.

spectral index distribution with the radio brightness in the three galaxies: a common feature is that brighter regions have a spectral index of about $\alpha \simeq 0.5-0.6$. In the faintest regions, the radio spectrum steepen to $\alpha \simeq 1.0-1.2$. The anticorrelation between the radio brightness and the spectral index causes a systematic steepening of the radio spectrum with the increasing distance from the center of the galaxies, where typically brightest regions are located.

Finally, we compared the spectral index distribution with IR brightness, obtained from 70 μm *Spitzer* images [9]. This emission can be used as a star formation diagnostic. Right panels in Figures 1, 2, and 3 show the radio spectral index versus 70 μm brightness. The radio spectral index shows a common behavior in all three galaxies: an anticorrelation exists between the radio spectral index and the infrared brightness. Regions in which the IR is higher than the average tend to have flatter radio spectra than their surroundings. The observed trend is expected from the local correlation between the radio continuum and the infrared emission. This result is also consistent with the idea that in regions of intense star formation, where the injection rate of electrons is presumably higher, the CR electrons' confinement time is shorter than their radiative lifetime, so the electrons efficiently escape from their birthplaces. The observed anticorrelation between radio continuum brightness and spectral index may imply that the cosmic ray density and the magnetic field strength are significantly higher in these regions than in their surroundings.

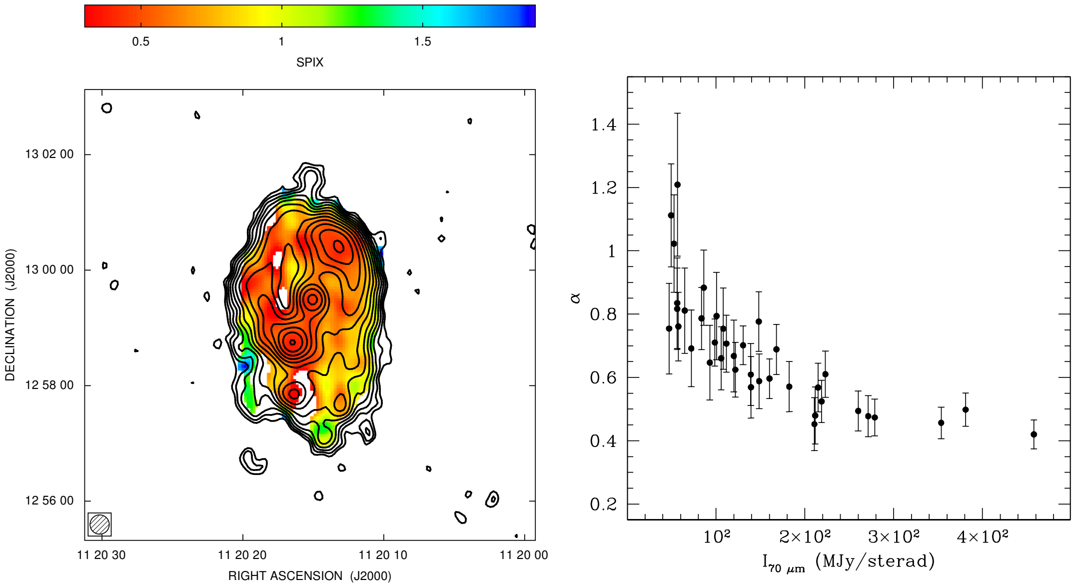

Figure 2: Galaxy NGC 3627 – *Left panel*: The color scale represents the image of the spectral index measured between 327 MHz and 1.4 GHz. Pixels with an intensity level above 3 σ at both frequencies have been considered. Contours levels of the radio image at 1.4 GHz, starting from 3 σ and scaling by a factor of $\sqrt{2}$, are overlaid on the image. The FWHM of this image is $20'' \times 20''$. *Right panel*: Point-to-point comparison between spectral index variation and IR-70 μm brightness. Only points exceeding 5 times the rms of the computed spectral index are shown. Figures taken from [8].

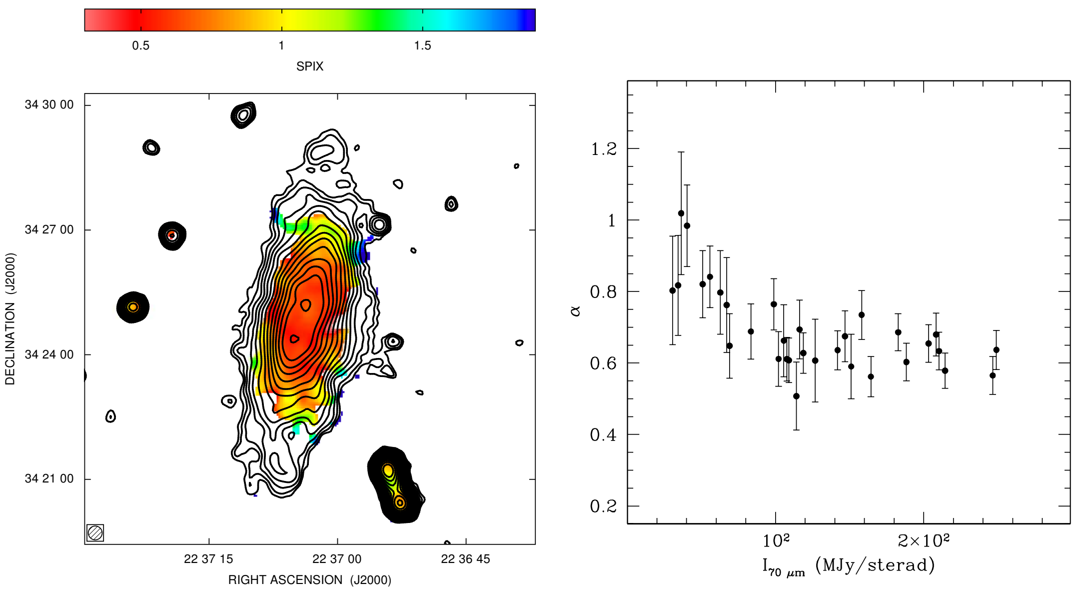

Figure 3: Galaxy NGC 7331 – *Left panel*: The color scale represents the image of the spectral index measured between 327 MHz and 1.4 GHz. Pixels with an intensity level above 3 σ at both frequencies have been considered. Contours levels of the radio image at 1.4 GHz, starting from 3 σ and scaling by a factor of $\sqrt{2}$, are overlaid on the image. The FWHM of this image is $20'' \times 20''$. *Right panel*: Point-to-point comparison between spectral index variation and IR-70 μm brightness. Only points exceeding 5 times the rms of the computed spectral index are shown. Figures taken from [8].

References

[1] Yun, M. S., Reddy, N. A., & Condon, J. J. 2001, ApJ, 554, 803

[2] Rickard, L. J., Turner, B. E., & Palmer, P. 1977, ApJ, 218, L51

[3] Israel, F. P. 1997, A&A, 328, 471

[4] Adler, D. S., Allen, R. J., & Lo, K. Y. 1991, ApJ, 382, 475

[5] Murgia, M., Crapsi, A., Moscadelli, L., & Gregorini, L. 2002, A&A, 385, 412

[6] Murgia, M., Helfer, T. T., Ekers, R., et al. 2005, A&A, 437, 389

[7] Paladino, R., Murgia, M., Helfer, T. T., et al. 2006, A&A, 456, 847

[8] Paladino, R., Murgia, M., and Orrù, E., 2009, A&A, eprint arXiv:0905.3643

[9] Kennicutt, Jr., R. C., Armus, L., Bendo, G., et al. 2003, PASP, 115, 928